Abstract
In this paper facts related to water resources management problems in the mining areas of Goa are presented. Possible solutions to some of the problems have been suggested to minimise the adverse impacts arising out of water resources abuse.

1.0 Background note:
Mining is an important activity for the economy of Goa and a significant foreign exchange earner of the state and the country in particular. Certain natural factors like the presence of coastline, a very good natural harbour at Mormugao and a number of navigable inland river systems have promoted the economic exploitation of the iron and manganese ores. The mining belt of Goa, an area of approximately 700 km² a little less than 20% of the Goa’s land area is concentrated in four talukas viz., Bicholim, Sattari, Sanguem, and Quepem.

With its beautiful undulating topography covered with lush green vegetation, clean and neat beach covered shoreline and a blend of urban-rural socio-cultural habitat make Goa the most unique place in the country. Environmentally still in a pristine state of preservation week, 98-99. Indian Bureau ®16 Mines Regional Office# GOA. Many of the mining companies have done and are doing a great deal of job to minimise the damages to the eco-system. At the same time it should be born in mind that mining activity without causing environmental degradation is an imagination. Infact the mere existence of the biosphere itself causes damage to the pristine environment of the earth. However, the violation of human rights.

2.0 Attitude of miners:
Many of the mining companies have done and are doing a great deal of job to minimise the damages to water resources environment but still lot need to be done. Whatever is done seems to be in sufficient and is without any R & D input. This has led to reckless exploitation and destruction of the precious water resources of this area. The results are now manifested in the form of contaminated surface and groundwater bodies, river water contamination, siltation of river beds and agricultural lands, depletion of groundwater storages and threats of salt water intrusion.

Need of the hour:
It needs no emphasis that the water is essential for survival. The heath of the water resources environment in the mining areas need to be assessed on a realistic basis so that ways and means can be developed for judicious management for sustainable growth. To achieve this both surface and groundwater resources should be monitored and estimated on a microcatchment level over the entire mining belt in Goa. The captains of the mining industry should comeout openly to provide all relevant and realistic data and information to the concerned authorities without prejudice. There is a need to earmark more funds for monitoring and managing the water resources to meet the aspirations of the local people and the environment as a whole. It would be appropriate here to introduce the concept of Mine Regulatory Zone (MRZ) for scientific management of water resources.

3.0 Case Study:
It would be surprising to note that so far there are only few hydrogeological studies that are carried out in the mining areas of Goa. It would be difficult to assign causes for not taking up detailed and systematic studies in the mining belt of Goa. However, we have initiated systematic hydrogeological investigations in the kudne river microcatchment covering areas of intense mining activities. As many as 49 open observation wells have been established for monitoring the groundwater levels on a periodic basis since April 1997. The hydrogeological studies indicate that the groundwater bodies are available under three different hydrogeological conditions viz.

i) In the top lateritic layer extending to a depth of about 20m below ground, the groundwater occurs under unconfined conditions. Most of the open wells in the villages and the agricultural fields tap this water for drinking, domestic and agricultural use.

ii) The powdery iron-ore bodies which are some time folded and invariably surrounded by various types of thick clay formations form confined to semi-confined aquifers. These are very potential fresh water bearing layers but most of this water is being drained by mine pit dewatering during mining.

iii) The third zone is located at the contact point between the clay layer and the bed rock which are jointed and weathered on the top surface.
These form another confined aquifer zone which are not yet exploited extensively.

The main source of recharge to all these aquifers is rainwater. Downward and lateral percolation of rainwater takes place through top laterites via iron-ore bodies and clay layers to reach the basement rock boundary. The schematic section of this process is depicted in Fig 1.

The mining managers who have great exposure to the field situations argue that the confined (deeper) and unconfined (top lateric) aquifers are two independent bodies and there are no interlinkages between them because of the intervening thick clay layers. This argument implies that the mine pit dewatering does not affect the shallow unconfined aquifer on which majority of the drinking water wells in the nearby villages depend. In figure 2 the water-table contours drawn using 46 observation well data indicate that the groundwater flow direction are generally directed towards the mining areas and close to the mine sites the contours become very steep thereby suggesting the contribution of shallow groundwater to the mine pits. The argument we would put forward is that the clay layers do transmit water through them but at a slower rates and hence recharge the deeper aquifers containing sometimes the original water. The insitu hydraulic conductivity determination for the clay layers and the periodic monitoring of the water levels by installing specially designed deep observation wells would convince the miners of the interlinkages of various aquifers at regional scale. Moreover the dryingup of the shallow drinking water wells in surrounding villages is not only linked with the interlinkage phenomena but also is related to the other activities of mining as indicated in the figure no 3. Therefore the scientific temperament should prevail upon the concerned rather than depending on local field realities.

4.0 Mining and drinking water wells:

Majority of the households in the mining areas use multiple sources of water for drinking and domestic purpose. Groundwater is the most predominant of all the sources which is extracted mainly through shallow open wells and some times tube wells. In major mining areas the dependence on groundwater is found to be about 57 to 84% (Teri, 1997). A significant number of households are also dependent on local rivers, streams, and springs for meeting their drinking water demands. The high dependence on ground water is because it had been a traditional source inherited from time immemorial. Besides, the piped water network are non extensive and highly irregular. Large number of shallow (normally 10 to 15m deep) open wells are in use throughout the mining areas. These wells are confined to the top lateritic layer in which the groundwater occurs under water-table conditions. These laterites get recharged during rainy season through fractures, joints and interconnected pores. The response of the groundwater levels to rainfall in few wells in the Kudnepissurle-Sonshi mining area is shown in Fig. 4. The lagtime between the rainfall peak and the shallowest levels of groundwater is about one month indicating slow process of recharge to the ground. The lowest water levels are generally noticed during June. The water table generally fluctuates between 2 to 6 m depth below ground. In figure 1 the schematic section show the dynamicity of the unconfined aquifer water levels in the undisected (pre-mining) topography in mining areas.

5.0 Base-flow reduction to rivers, lakes and springs:

Many surface water bodies like rivers, ponds, lakes, springs, etc. despite heavy water losses through evaporation and seepage during summer still contain water in them. The main source of water feeding to these water bodies is form groundwater which slowly percolates through ground after getting recharged during the rainy season. This contribution is referred to as base-flow or lean period flow. Any groundwater extraction structures situated in and around the surface water bodies could reduce, divert or stop the contribution of groundwater to these surface water bodies thereby rendering them dry. Mining is one of such activities. Instances of mining close to riverbeds, lakes, springs and other surface water bodies are not uncommon in Goa. The base flow normally get reduced in the mining areas due to three main factors, viz.

1. The cutting and dissecting large surface areas for mine related activities reduces the intake area (recharge area) of rainwater and hence quantity of groundwater storage.

2. The dumping of large quantities of mine wastes consisting mainly of impermeable clays on the natural surfaces inhibits the natural rates of rainwater recharge into the ground and hence reduction in subsurface storage volumes and subsequent base-flow...

3. When dewatering of the mine pit is carriedout large portion of groundwater is also pumped. Due to continuous pumping from the mine pits the cone of depression spreads around the pit area and drains the groundwater towards it. This would not only reverse the base-flow direction from surface water bodies towards mine pits but also the surface water bodies would contribute water to the declining water-table below them if these water bodies fall in the area of cone of depression.

The schematic section of a mine located near a river is shown in figure 5. The corresponding likely behaviour of the base-flow hydrograph under such circumstances is shown in figure 6. It is seen from figure 6 that due to mine drainage the base-flow contribution is reduced and on the other hand the time to peak of hydrograph is decreased while flood peak is increased. This is due to siltation of the river courses and rapid collection of the surface run-off from the dump sites.

6.0 Damage control measures:

In order to minimise the water related socio-environmental problems in the mining areas the following damage control measures can be assessed for adoption.
1. The foremost among the water related problems seems to be the drinking and domestic water in the villages of mining areas. As discussed the mining activities in some areas has definitely caused drying up of water wells in villages located in proximity to working mining pits, to solve this problem the options could be;

i) the direct option involves providing needed supplies by tankers which is being already done by few miners, or provide water by drilling deep bore wells in the villages.

ii) the indirect way is by enhancing the groundwater storage in the affected top laternic aquifer. This could be achieved by way of artificial recharge using deturbidised pit water. The most efficient and economic way would be to dig trenches of appropriate dimensions paralleling the hill contours and filling these trenches with pit water to percolate downgradient through the laterites. This will recover the groundwater levels in the downstream localities and villages. Mechanisms to protect these treches from sitting during the rainy seasons should be provided. The schematic section of such method is shown in figure 7.

2. The second most important problem faced by the miners as well as the general environment is the generation of large quantities of turbid water both from mine pits and from beneficiation plants. The present methods of deturbidising are not economical and effective. Many a time the situation are such that the highly turbid waters have to be let into the natural systems which has posed dangers to surface and groundwater qualities besides siltation of water courses and agrolands. This root cause of turning freshwater into turbid water has to be tackled effectively. The following ways could be tried to;

i) Installation of dewatering wells around the mine pits so that the groundwater is takenout before it reaches the mine pit, this also provides cone of depression for working in the pit under dry conditions. The pumped water will be free from turbidity and can be directly used for any purpose. However, this requires bit of detailed survey and planning for dewatering system.

ii) Other way of achieving the minimum groundwater flow to mine pits would be to encourage intensive use of groundwater for agricultural, industrial, drinking and domestic purposes so that water levels are lowered essentially around the mines.

iii) The third way could be to make use of abandoned mine pits for discharging the turbid pit water so that the turbidity get reduced over a period of time and the groundwater also get recharged by downward percolation from the storage pits. If need be this water can be used for other purposes depending on the turbidity levels.

iv) If waste dumps are designed properly to provide a large depression on the top to accommodate the pit water the turbidity problems can be minimised to some extent. These artificial lakes on dumbs would provide greater opportunity for evaporation and percolation into the dump thereby reducing the volume of water to be handled. However, the possible risks of failures of such lakes should be evaluated alongside feasibility studies.

3. The mine waste dump sites are the other sources from where the surface run-off gets contaminated. Unless these dums are stabilised and aforsted the problem would remain to be potential. In order to reduce this problem the dumps should be provided with inward sloping benches similar to benches in the mine pits at regular spacings. These benches should be so designed so that the water coming on them is transported along with inward edge of the bench to be passed to next lower bench. This way the spiral looking benches can bring the rainwater more smoothly to the lower levels and at the same time provide greater contact time for percolation into the dump. The likely scouring along the inner edges of the benches could be reduced through aforestation.

4. The implementation of the little thought plans of augmenting the river flows using pit water could be counter productive if the quality of water does not meet the stipulated levels.

5. The concept of refilling the abandoned mine pits should be subjected to greater debate because refilling possibly add to further groundwater contamination due to likely aerobic chemical reactions of wastes with percolating water.

7.0 Recommendations:

The following recommendations are made for consideration of the concerned for further action to improve the process of water resources management in the mining belts of Goa.

1. The entire mining belts should be classified into different zones based on the degree of impacts of mining. The mining companies should take collective responsibility to give top priority to meet immediate requirements of rural drinking water demands in the affected villages.

2. The Indian Bureau Mines (IBM) should establish a strong and independent water resources division to takeup detailed studies in and around mining areas or it should support and encourage R & D facilities at the local academic institutions through funding.

3. The captains of mining industry should wholeheartedly come forward to share the realistic data about water resources and management with the academicians and researchers so that workable and acceptable solutions can be evolved.

References:

1. Top Laterite - Unconfined aquifer
2. Iron ore body - Confined aquifer
3. Top of basement rock - Confined aquifer

Note: Rainwater percolates, down to basement rock through laterite via iron-ore body as well as clay layers.
Pre-mining water level. Mine pit (Loss of recharge area).

THE PROBLEM

Laterite

Original water-table (Before mining)

Post-mining water-table

Ore body (Confined aquifer)

Various clays

Basement rock

FIG. 3

HYPOTHETICAL CROSS-SECTION OF MINING AREA IN GOA

Pre-mining water level. Mine pit Loss of recharge area.

Laterite

Recharge pit

Recovered water table

Village

FIG. 7 HYPOTHETICAL CROSS-SECTION OF MINING AREA IN GOA

THE SOLUTION
Fig. 4: Correlation of rainfall with ground water levels with time.
Working mine pit with water at bottom

**FIG : 5** WORKING MINE PIT CLOSE TO RIVER LEADS TO DEPLETION OF NOT ONLY BASE FLOW TO RIVER BUT DIVERTS RIVER FLOW TOWARDS MINE PITS

Cake of clay and silt (impermeable)

**FIG :** ABANDONED MINE PIT REGENERATING THE BASE FLOW TO RIVER TO A LIMITED EXTENT (Once pit water level falls below clay and silt cake, base flow will stop)
Fig. 6: Base-flow hydrograph in mining areas